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ABSTRACT

Almost all the bridge footings in southern California are on piles due to the soil condition. Steel (H & W), reinforced concrete and steel pipe filled with reinforced concrete are common piles that are using at bridge abutment and bent footings. Various methods and procedures are available when using known driving energy to determine the bearing capacity of the pile. These procedures can be categorized into three areas: (1) pile driving formulas, (2) wave equation analysis of pile driving, and (3) dynamic pile driving analysis.

Pile driving formulas all utilize the energy delivered per blow, the resistance to movement of the pile per blow, pile penetration, and some acknowledgement of the unknown produced by all components, which act to drive the pile. All of the driving formulas make use of the conservation of energy theory:

(Hammer energy) – (Energy losses) = (Work performed) (1)

Soil resistance multiplied by pile penetration represents work performed, hammer stroke multiplied by ram weight represents hammer energy, and various factors and/or constants in driving formulas represent energy losses in the piling system.

Gates formula is formally accepted by Caltrans to consider the pile capacity per number of blows per 300mm pile penetration. In lieu of static load test the typical method for determining load-bearing capacity of a pile depends on knowledge of the energy used to drive the pile.

When the pile has been driven to the specified tip elevation but the specified bearing value as determined by the Gates formula has not been obtained the contractor is allowed to keep about a foot of the pile above the ground to do the retap after a set period. Trial and error method would be employed or minimum of 12 hours unless bearing is obtained sooner during the retap process. Application of the Gates formula is the basis of acceptance, and pile penetration is measured over the last few blows. In fact most engineers prefer to use the more conservative approach and determine the penetration by counting the number of blows per foot or half foot. The point of retap is to emphasize the ground take-up that has taken place over a given period.

In this paper besides considering more than 2000 piles that some of them were accepted after retapping, the relation between the elastic rebound theory and the increment of blows over a given period will be presented.

INTRODUCTION

From 2001 up to now we were involved in more than 2000 piles including H & W (steel), reinforced concrete and steel pipes were driven to carry the bridge abutments, columns load and pump plant structures. About seven percent of these piles did not meet the required of blows per one foot pile penetration. ENR and gates formulas were used to consider the pile capacity. In these cases the contractor allowed to leave at least two feet of the pile above the grade and retap it the following day. In these 2000 piles all the retapped piles were meet the required blows per foot of pile penetration.

From 2001 we started investigating regarding soil behavior improvements by finite element model for the soil under the pile punching force. Bottom bearing capacity for the reinforced concrete and H or W steel piles should be increased from top to the bottom, so it could not be the answer for the soil improvements. Based on the results form the models the differences in lateral bearing behaviors were the reason for the soil capacity improvements.

ELASTIC REBOUND THEORY

If you blow up a balloon, the addition of air causes the balloon to expand. If you then squeeze the balloon with your hands the balloon will change its shape. Removing your hands causes the balloon to return to its original shape. If you take a thin board and push the ends toward each other, the board will bend. If you let the board go, it will straighten out again. This is called elasticity.

When air is blown into the balloon, when the balloon is squeezed, or when the board is bent, strain energy is stored up inside the rubber walls of the balloon and within the board. When the balloon is released, or the board is let go, the energy is released as the balloon and board return to their original shapes (Fig, 1).

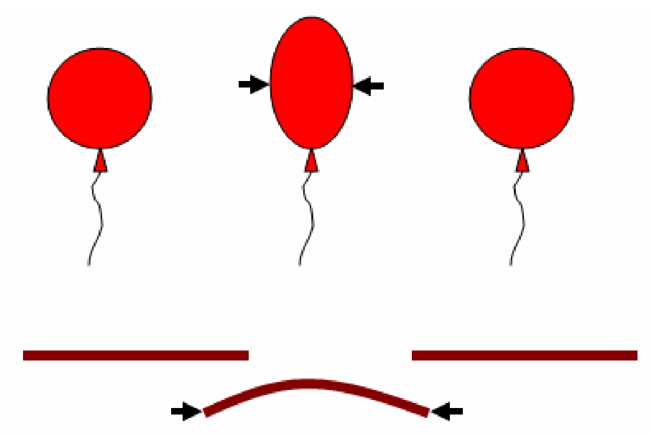

Fig. 1. Balloon and board elasticity

It isn't easy to picture rocks as being elastic, but they are. If a rock is squeezed in a laboratory rock press, it behaves like a rubber ball, changing its shape slightly. When the pressure of the rock press is released, the rock (or the rubber ball) returns to its original shape just as the balloon or board does. But if the rock press continues to bear down on the rock with greater force, ultimately the rock will break, like the board or balloon.
This slow movement was in the same direction as the sudden movement during the earthquake. Strain accumulates in the crust until it causes the crust to rupture in an earthquake, like breaking the board and popping the balloon.

If a straight fence is built across the fault as in plate moves, it gradually distorts the fence. Just before an earthquake, the fence has an "S" shape. When the earthquake occurs the distortion is released and the two parts of the fence are again straight; but now there is an offset.
This diagram greatly exaggerates the distortion. Actually, the distortion is spread over many miles and can only be seen with precise instrumentation (Fig. 2).

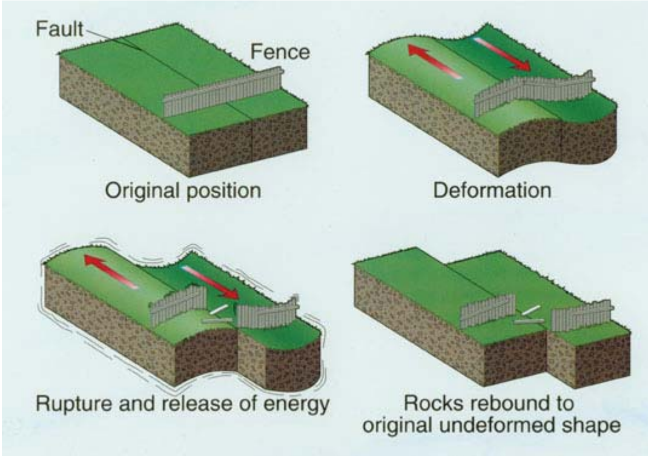

Fig. 2. Elastic rebound theory illustrations

Soil Capacity Improvement

To present the soil capacity improvement according to the elastic rebound theory and during retapping process, Figure 3 is shown different soil layers before and after earthquake that it can be used for pile driving.

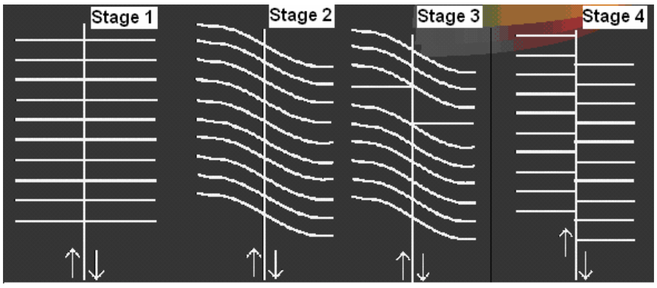

Fig. 3. Elastic rebound theory and different soil layers

Four stages can be considered as follows:
Stage 1: features aligned after previous earthquake;
Stage 2: strain builds up, deforms crust near fault;
Stage 3: earthquake rupture starts at weak spot on fault;
Stage 4: rupture spreads to other parts of the fault; return to stage 1.
Based on these divisions, four stages for pile driving can be provided that are shown in Fig. 4.

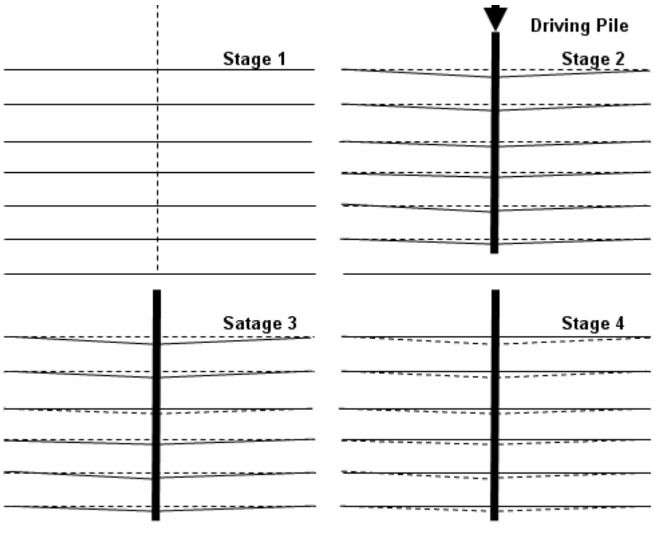

Fig. 4. Elastic rebound theory and pile driving

These four stages would be:
Stage 1: Bottom of the footing is ready for pile driving and all features are aligned;

Stage 2: Pile has driven about two feet above the final tip elevation (did not meet the required blows). In this stage solid lines showed the deformed layers and dashed lines showed the original layers before driving the piles;
Stage 3: Few hours later starts to return to stage 1;
Stage 4: After a day most parts of the soil layers returned to stage 1.

Big difference between pile driving and an earthquake from rupture spreading view are directions (vertical verses horizontal) and concentrations (line verses plane plate). In pile driving strain builds up and deforms soil near pile, so pile would act like as a fault, and ruptured soil around the pile (fault) will turn to the original position. It is important that the plastic deformation will not return so some part of the deformation will return and this part will increase the blows number for retapping a pile.

Types of Piles, Soil Conditions and Hammers

Figures 5, 6 and 7 showed different types of 2000 piles that we were considered in this investigation.

Fig. 5. Battered steel pipe piles ready for retapping)

Fig. 6. Reinforced concrete pile driving

Fig. 7. Steel (H) piles after driving and retapping

Based on the geotechnical reports the soil profiles consisted of sandy clay (CL), sandy silt (ML), silty sand (SM), clayey sand (SC), lean clay (CL), and fat clay (CL) from top to the bottom of the piles.

Delmag 36-32 and differential acting steam/air (piston drop 20” and minimum inlet pressure 120psi) hammers were used for driving these 2000 piles. Table 1 shows the pile capacity verses hammer stroke and blows.

Table 1 Pile design capacities and Hammers data

Pile Design capacity(kip)	Hammer	Stroke (ft)	Number of Blows	
			Plumb	Batter
180	Delmag 36-32	7	23	24
		7.5	21	23
		8	20	21
185	Delmag 36-32	7	24	25
		7.5	22	23
		8	21	22
202	Delmag 36-32	7	27	28
		7.5	25	26
		8	23	24
202	Diff. Acting	1.67	85	90

To show the soil capacity improvement after retapping the driven piles in following day (about 18 hours later), Table 2 shows the recorded data (sample) for steel pipe piles (design load 202kips) before and after retap process using a Delmag 36-32 hammer. End bearing capacity for these piles was too small and negligible. Figure 8 is illustrated the Table 2 data and as it can be seen all the blows after retapping are improved more than 50%.

Table 2 Strokes and blows before and after retapping

Before Retap		After Retap	
Stroke(ft)	Blows	Stroke(ft)	Blows
7	19	7.5	28
7	13	7.5	26
7.5	14	7.5	26
7	17	8	23
7	14	8	24
7	18	7.5	30
7.5	16	7.5	27
7.5	15	7.5	25
7.5	17	7.5	34
7	17	7.5	34
7.5	20	7.5	24
7	14	7.5	28
7	14	8	22
7	12	8	21
8	15	7.5	30
7.5	15	7.5	38
7.5	16	7.5	33

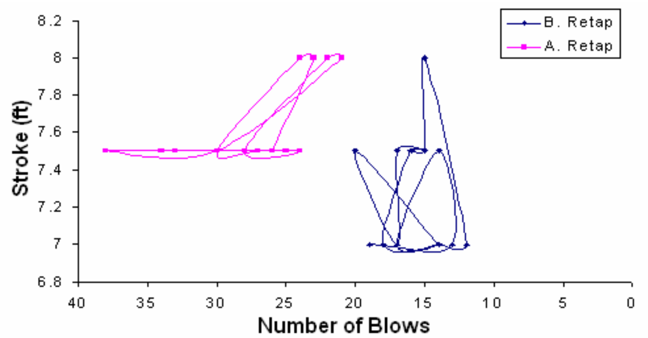

Fig. 8. Number of blows before and after retapping

CONCLUSIONS

In cohesive soils and some granular soils the ultimate capacity of driven piles is subjected to change with time during or following driving. Pile driving can create a manmade fault that with each hammer blow, fault would be activated and a very small earthquake will be created around the pile. Some times slopes around the driving area might be eroded by this manmade earthquake.

Three different zones around a driven pile can be observed. First cylinder around the pile (pile in the center of the cylinder) would be in plastic limit with almost permanent deformations (plastic zone), the second cylinder would be in elastic limit (elastic zone) and as soon as vibration stops it will starts to back to its original shape (re-bound). The third cylinder would be almost without deformations (not active zone). In all 2000 cases these three cylinders were observable. The thickness of the first cylinders around the piles were less than a foot, and the thickness of second cylinders around the first cylinders were about few feet. The second cylinders are the sources that can increase the number of blows after following driving, and due to the pile driving this part would be in passive mode (Fig. 9).

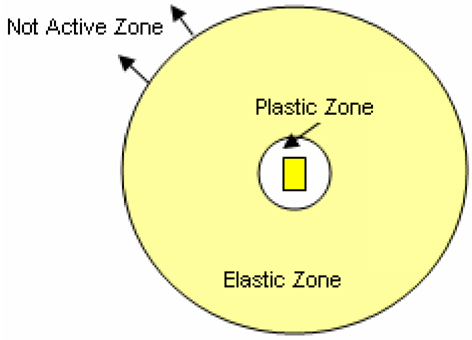

Fig. 9. Three different zones around a pile

REFERENCES

Office of Structure, State of California [2001]. “Soil Reinforcement Program”, Department of Transportation, pp. 73-96.

Zandparsa, K. [2002), “Improvement the Lateral Pressure Distribution of Adjacent and Distance Surcharge and KZP1 & KZP2 Methods”, Proc. Structural Engineers World Congress, Yokohama, Japan.

ZandParsa, K. [1994]. “Loading, Volume 2”, Elm & Sanat 110, Tehran.

Winterkorn, H.F. and Fang, H.Y. [1756]. “Foundation Engineering Hand Book”, Van Nostrand Reinhold Company, New York.

Raymond, G.P. [1997]. “Geotechnical Engineering”, pp. 168-169.